Exergy analysis of a production process of Fischer-Tropsch fuels from biomass

K.J. Ptasinski ,T.Loonen, M.J. Prins*, F.J.J.G. Janssen
Department of Chemical Engineering, Technical University of Eindhoven,
PO Box 513, 5600 MB Eindhoven, Netherlands
Fax: +31-40-2446653; M.J.Prins@tue.nl

An exergy analysis of a Biomass Integrated Gasification – Fischer Tropsch process is presented. The analyses were done for an air-blown, atmospheric gasifier using poplar wood as feedstock. Results show that the rational (exergetic) efficiency is 51.2 % for the combined liquid and gaseous products. The effect of process parameters on the rational efficiency is demonstrated.

Introduction

The conversion of biomass materials to liquid fuels is a subject of much research. Direct liquefaction of biomass has been demonstrated using technologies such as fast pyrolysis and hydrothermal upgrading. There has been recent interest in an indirect liquefaction of biomass, whereby the biomass first is gasified, followed by the conversion of the formed synthesis gas to Fischer-Tropsch liquids. In order to allow a fair comparison of these biomass-to-liquids processes, they must be compared on the same basis. Exergy analysis (sometimes referred to as availability analysis) is based on the first and second law of thermodynamics and offers an objective and quantitative criterion to do this [1].

Another advantage of exergy analyses is the fact that integrated processes can be optimised with regard to thermodynamic efficiencies. This is relevant because a thermodynamic improvement in one unit may have negative repercussions in others units. This paper focuses on optimised process integration between a biomass gasifier and a Fischer-Tropsch unit for the production of fuels.

Approach

The analysis was done for a feedstock of poplar wood, containing 50 wt% moisture, 1.32 wt% (dry basis) ash, and an organic fraction consisting of 49.1 wt% C, 6.0 wt% H, 44.3 wt% O, 0.48 wt% N, 0.01 wt% S and 0.1 wt% Cl [2]. Chemical exergy of the wood was calculated from the lower heating value (18.24 MJ/kg, m.a.f.) using the method of Szargut and Styrylska [3].

The standard process from biomass to Fischer-Tropsch liquids was modelled in Aspen Plus (version 10.0) in the following way:

1. Drying: biomass is dried from 50 wt% moisture to 20 wt% moisture using indirect drying. Reaction heat from the Fischer-Tropsch section is used for this purpose.
2. Gasification: the gasifier is air-blown and autothermally operated at 900°C and atmospheric pressure. Thermodynamic equilibrium is assumed, as is common for fluidised bed gasifiers.
3. Gas clean-up: the gas is cooled to 150°C, ash particles are separated by filtration and acid gases are washed by water from the synthesis gas.
4. Gas compression: The gas is compressed from atmospheric pressure to 25 bar using an adiabatic compressor with isentropic efficiency of 0.72.
5. Shift conversion: the synthesis gas is catalytically shifted at a temperature of 330°C. Carbon dioxide is removed by absorption in an organic amine solution.
6. Fischer-Tropsch synthesis: the gas is converted to gaseous and liquid hydrocarbons at a temperature of 240°C. An Anderson-Schulz-Flory distribution is assumed for the product distribution with a growth factor alpha of 0.95. The total single-pass H_2+CO conversion is 80%.
7. Fischer-Tropsch work-up: a flash is done at reaction conditions as this represents the G/L separation taking place in the reactor itself. Liquids entrained in the tail gas are condensed under cryogenic conditions. The liquid products are considered the final products: these will be transported to a refinery for further work-up (e.g. fractionation, hydrocracking and/or hydroisomerisation).

Results

For the standard process, the rational efficiency (defined as exergy content of the Fischer-Tropsch products divided by the exergy content of all input materials, heat and work) amounts to 51.2%. This can be subdivided between 38.5% for the liquids and 12.7% for the tail gases. The exergetic content of the tail gases can be utilized for the production of electricity. Including a gas turbine/steam turbine combined cycle (with electrical efficiency of 50%) would bring the electrical efficiency to 6.5%. As is normally the case for exergetic efficiencies, these are slightly lower than the efficiencies based on higher heating values reported by other authors. [4]

The rational efficiencies and the relative exergy losses for each section have been evaluated, showing that the major exergy losses occur during gasification (over 50% of the total losses). To reduce these losses, process improvements such as using oxygen or enriched air can be considered.

The quantitative effects of the process parameters, such as amount of evaporated moisture in the drier, gasifier temperature and pressure, degree of conversion and alpha value in the Fischer-Tropsch reactor, have also been evaluated. As an example, we have observed that the total rational efficiency goes through a maximum as a function of the operating temperature in the gasifier. A too low temperature in the gasifier (< 600°C) results in a too low carbon conversion and methane formation, while a too high temperature (>1000°C) requires a higher equivalence ratio leading to irreversibilities in the gasifier.

Conclusions

Exergy analysis is a useful method to evaluate the thermodynamic efficiencies of biomass conversion processes. We have demonstrated that the exergetic efficiency of producing Fischer-Tropsch fuels from biomass is quite high (in the order of 50%). This forms a solid thermodynamic base for introducing these synfuels. The main exergy losses take place during gasification. Finally, the thermodynamic efficiency can be optimised with regard to the process parameters.

References

[1] K.J. Ptasinski, C. Hamelinck, P.J.A.M. Kerkhof, 'Exergy analysis of methanol from the sewage sludge process', Energy Convers Mgmt, 2001 (in press)
[2] R. van Ree, A.B.J. Oudhuis, A. Faaij and A.P.W.M. Curvers, 'Modelling of a biomass-integrated-gasifier/combined-cycle (BIG/CC) system with the flowsheet simulation programme Aspen^{plus}, ECN report ECN-C--95-041, Petten, june 1995.
[3] J. Szargut, T. Styrylska, 'Approximate evaluation of the exergy of fuels (in German)', Brennst. Wärme Kraft, vol. 16, no. 12, pp. 589-596, 1964
[4] E.D. Larson, H.Jin, 'Biomass conversion to Fischer-Tropsch liquids: preliminary energy balances', presented at the 4th Biomass Conference of the Americas, Oakland, 1999